# Analysis of Hybrid Energy Storage System Integrated with Microgrid

SHORT SYNOPSIS

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*by*

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## SCHOOL OF ENGINEERING & TECHNOLOGY

### Certificate

I hereby declare that the short synopsis "**Analysis of Hybrid Energy Storage System Integrated with Microgrid**" being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Engineering under faculty of Engineering & Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2023-24.

It is a bonafide record of original work carried out under the supervision of **Dr. Amarinder Kaur** and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free, and proof has been submitted.

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**Abstract**

India has set ambitious goals for itself to transition to clean energy as the global journey toward decarbonization. The country has pledged to achieve net-zero emissions by 2070 and has also made several commitments, including reducing carbon intensity, reducing emissions, and providing growth of energy capacity from non-fossil fuels. The environmentally harmful $CO_2$ emissions and the limited reserves of fossil fuels have provided the impetus for the introduction of new renewable technologies.

The energy sources in a microgrid (MG) are often distributed generation technologies like solar, wind, fuel cells, batteries, etc. However, due to variability of PV & wind power characteristics, MG s experience more power fluctuations. Energy storage is employed, to bridge the gap between power Generation & user demand as well as improves the grid stability and reliability. Also, Energy storage make the MG more efficient by reducing the waste of Renewable Generation. The advantages of AC as well as DC systems are combined in a hybrid AC/DC microgrid, which also makes it easier to incorporate different energy sources.

In the proposed study, the power management of the hybrid MG will be studied, which consists of tracker-based PV modules, wind turbines, battery storage, pumped hydro storage and fuel cells as energy sources, and hydrogen electrolyser system to store the generated surplus power. The solar PV and wind turbine best configurations with hybrid storage systems emphasize increasing the proportion of renewable energy sources (RES) while lowering the cost of energy (i.e., LCOE).

**Key Words**: HESS (Hybrid Energy Storage System), Hybrid Ac/Dc microgrid, Tracker Based Solar PV system, Wind Turbine, HOMER Pro.

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## 1. INTRODUCTION:

Renewable energy (RE) is a promising form of power generation as declining reserves of traditional fossil fuels. Photovoltaic (PV) and wind turbine generated power are widespread worldwide because of the advantage of free use and environmental friendliness. However, renewable power generation is subject to uncertainties and intermittency, which remains to be barriers to its application.

### 1.1 Hybrid AC/DC Microgrid:

In the traditional AC microgrid (MG), multiple energy conversion reduces efficiency, while in the DC microgrid, fewer conversion processes increase efficiency. In AC microgrid, continuous reactive power loss decreases efficiency, while this is not the case in DC microgrid. Synchronization is required in the case of AC, but not in the case of DC.

A typical structure of hybrid MG consist of an AC grid, a DC grid, a utility scale grid and an interlinking stage. In this configuration, as mentioned in Fig 1., AC & DC both systems linked to distributed energy generators, various energy storage systems and the load. The interface converters were used to interface between the sub grids AC & DC. This arrangement limits the number of interfaces, which in turn reduces costs and increases overall efficiency and reliability.

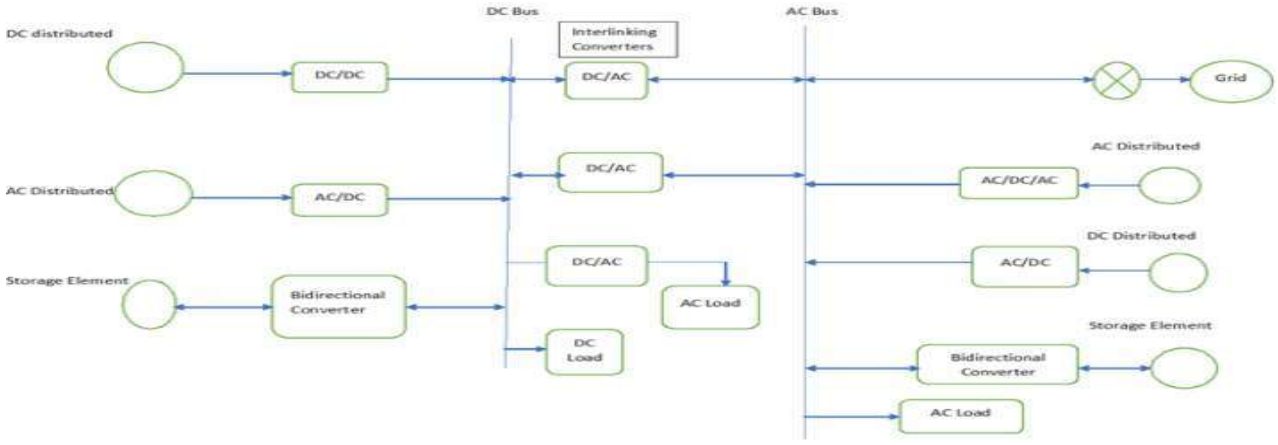


**Fig 1.** AC/DC hybrid MG

## 1.2 Hybrid Energy Storage System (HESS):

Integration of Energy storage system along with RE sources is the best solution to cater the problem of inherent intermittent nature. The excess energy would be stored in energy storage system (ESS) from RE sources and used to meet the electrical demand during the shortage of generation. Integration of such ESS could increase the techno-economic viability of Renewable energy sources, which mainly depends on CAPEX (capital expenditure) as well as technical specification of Energy storage systems. Technically, the energy storage system provides improved power quality and stability to the power grid through its stabilizing effect on the grid during the peak period of imbalance between supply and demand.

An electrolyser, which separates water molecules into hydrogen and oxygen molecules, can produce hydrogen, a form of energy carrier. This procedure is known as electrolysis and for this chemical process electricity is used as energy source. The produced hydrogen can be kept in storage to fulfil the remaining energy requirements. This transformation can occur through a fuel cell, where Hydrogen molecule combining with oxygen to produce electricity as well as water. This change of energy into electricity by HESS consists of three parts:

-Hydrogen generation
-Hydrogen storage
-Generation of electricity

In battery energy storage system (BESS), battery is charged first when the excess energy is not more than or equals to the critical charging power. When the battery charge reaches maximum state of charge (SOC) limit, the extra power utilized to produce $H_2$ in the electrolyser. If the remaining power exceeds the charging threshold, hydrogen generation in the electrolyser is preferred. When the $SOC_H$ equivalent of the $H_2$ storage tank reached to maximum limit, the system switched to battery charging. At the time of discharge, if the energy storage system's required power output is less than or equal to the discharge limiting power, the fuel cell begins supplying power. If the demand power exceeds the discharge threshold, the fuel cell takes precedence in providing power. At the time of discharge, when the required power output of the ESS is not more than or equals to the discharge critical power, the fuel cell starts to be

delivering power. If the power demand is higher in comparison to threshold discharge power, in that case fuel cell has priority to deliver power. When the $SOC_H$ equivalent of the $H_2$ storage reaches the minimum limit, ESS is selected as the battery that supplies the system unmet power.

Due to delay in Pump hydro storages (PHS) response by four-minute and inability to respond quickly enough, hence the PHS won't handle demand during this period. If the need for energy demand does not change during the hour, the utility grid can fulfil the demand during these delay period. The amount of energy supplied by main grid is determined by multiplying the hourly demand to 15. To strengthen the autonomy of the power system, PHS and short-duration ESS may be hybridised. During the PHS's response delay period, short-duration ESS will meet the demand. For instance, due to its quick response time, Hydrogen fuel cell (HFC) can serve as a short- duration storage solution to fulfil energy requirements.

Hence, hybridization of energy storage systems of Optimal configurations of PV and wind systems may maximize the RES share with least cost of energy which is equivalent to main grid tariff. Integration of energy storage with renewables, power system will be more flexible and reduces gap between energy demand and energy generation.

In the proposed study, five scenarios Studied to analyse the impact of using storage systems: in first case, PV with a battery energy storage system (BESS) & Supercapacitor(SC), in the second case, PV and wind system with a $H_2$ fuel cell (HFC) storage, in third case, PV and wind system with an HFC & a pumped hydro storage system (PHS),in fourth case PV with BESS with an HFC and finally, a PV and wind system with BESS with an HFC system.

## 2. LITERATURE REVIEW:

### a) Solar PV with BESS and SC

Pemila maniIn et. al. studied a common bidirectional converter based on Arduino was used to demonstrate that hybrid AC-DC MGs provides the benefit of improved efficiency by reducing the losses in the DC-to-DC

conversion and the noise in the AC circuits. Authors compared to a traditional system and found power conversion losses decreases up to 20–30% and increases efficiency levels significantly [1].

Nayeem Ur Rahman Chowdhury et. al. focused on modelling storage controller for different load characteristics. The authors discover that a DC MG platform with various load schemes can successfully regulate two separate storage systems. Both resistive and inductive load characteristics were modelled. A control system based on PI controllers regulates voltage and current. Based on the output data from the voltage and current controller, the battery charge controller regulates the battery charge and keeps track of the predetermined set points that support coordinated control between the storage devices. The authors point out that a variety of energy storage technologies can be used to operate DC MG and that the storage technologies can be deliberated based on load[2].

Cherechi Ndukwe et. al. proposed the designing a dynamic model of a standalone microgrid with a battery storage system. Here, the extra electricity generated during solar hours is utilized for charging the battery storage system. The battery provides the grid with stored energy on night-time when the PV systems are unable to produce energy[3] .

Mohd Alam et. al. investigated that the system with a lithium-ion battery (LI) generates more electricity and draws less electricity from the grid to meet the load demand on an annual basis. In comparison to lead-acid batteries (LA), the use of lithium-ion batteries for grid-connected MGs may be more feasible and cost-effective over the whole life cycle. The capacity of LA battery decreases much faster during the lifetime than that of the LI battery. The authors found that the power generation cost of LI battery is lower compared to LA battery storage-based MG. Therefore, LI battery is preferable for the grid-connected MG system even though the additional initial cost for the complete system is added [4].

Mohammad Amin Jarrahi et. al. introduced a newly proposed method for control & operation of a DC MG that includes solar PV, battery & supercapacitor and is based on an improved power control method using DC bus voltage changes to manage battery power, PV and supercapacitor. The authors discovered that this MG could satisfy the load requirements in both grid-connected and islanded modes. The authors also demonstrated that the control method gives the supercapacitor responds to changes in load more quickly than the battery. By using the control system, the battery gives durable power, and the voltage of the DC link remains within the allowable range [5].

**b) Solar PV /Wind and Hydrogen Fuel Cell**

M. Becherifa et. al. studied a new techno-economic solution, hydrogen-based energy storage technologies, which are a mature option for both economic gains owing to excess production of hydrogen and oxygen as well as, for stabilising the power system when there is an imbalance in electricity generation and demand. Compressed hydrogen may be stored in cylinders and can be supplied for use in hydrogen powered vehicles or MGs or straight to the main grid[6] .

Ashwini Mudgal et. al. has developed a concept where PV and main grid work in combination to meet the load demand. Moreover, PV has priority over the utility grid. FC is also integrated into the MG system. The authors focused on PV-FC MG with priority order solar PV, Fuel cell and lastly grid power. PV-FC Hybrid system shows that the utilization of $H_2$ as a storage and generation of energy[7].

Said Mohamed Mariama et. al. developed an idea for the electrification of a rural area with a MG, based on RE generation with $H_2$ storage and considered all possible scenarios in terms of the mix of PV-wind- PAC - electrolyser-storage to achieve the configuration with the lowest kWh price[8].

Jinsong Kang et. al. developed a solar photovoltaic, HFC and hybrid energy storage-based control and power management system to meet the stability requirements. The power sources consist of a fuel cell and PV solar. The hybrid energy storage technology, which combines a battery with an ultracapacitor, reduces fluctuation by taking use of variations in response traits. The system maintains grid stability amid solar energy fluctuations and significant load shifts by controlling the MG by monitoring the parameters of every module of MG[9].

Kuldeep Kumar et. al. has significantly contributed to present MG, in order to fulfil load demand, the PV generator serves as the main power source, and extra PV generated power used for production of $H_2$ in an alkaline electrolyser. The hydrogen produced by excess solar power is stored in MH container. Using the PEMFC generator, this stored $H_2$ is transformed again to electric power. In a standalone application, the MG (PVFC-B) with combined hydrogen and battery storage has a considerable reduction in LCOE[10].

Saif Mubaarak et. al. developed a new concept in which the authors analysed the effects of the four primary PV tracking methods on the system's technical and financial performance. The authors discovered that a) vertical single axis trackers (VSAT) are better option to produce the maximum power output, b) PV penetration of solar energy into the grid was higher as measured using a vertical single axis tracker, and c) VSAT demonstrated maximum sell of energy to the grid than any other tracking system. d) VSAT showed the lowest $CO_2$ emissions, and e) VSAT optimises the technical performance and leads to a decrease in the economic cost of proposed system[11].

Abozar Hashemi et. al. presented a hybrid system, made up of a wind turbine generator, an electrolyser, a hydrogen storage tank, and a fuel cell. This system works by feeding the electrolyser unit by excess electricity

produced by the wind turbine during off-peak hours, where water produces hydrogen and oxygen by the process of electrolysis. The hydrogen and oxygen that have been transformed are compressed and kept in tanks. During times of high demand, stored Hydrogen feed into the fuel cell to produce power (when the energy produced by the wind farm is lower than the demand). The hybrid system determines COE & NPC for the hybrid system and boosts the wind farm's capacity significantly[12].

Saif Mubaarak et. al. develops an independent PV/hydrogen/FC hybrid energy management system to handle intermittent PV. The system was planned to use an organised approach to optimal setup and energy planning. The authors make the system economically viable and tuned to peak load performance for smooth flow in peak load demand by using the FC configuration only to satisfy the load demands in peak hours[13].

Mashael A. Rajeh et. al. by using System Advisor Model software (SAM), compared economic analyses between two PV systems with and without hydrogen storage and evaluated the payback duration, internal rate of return (IRR), and other financial factors[14].

### c) Solar PV /Wind with Hydrogen Fuel Cell and Pump Hydro Storage

Loiy Al-Ghussain et. al. has been investigated, to increase the power system's autonomy how pumped hydro storage (PHS) can be combined with short-term energy storage to satisfy demand during the lagging response period of PHS. To maximize the Renewable energy share with keeping the cost of Energy equal to grid tariff, the hybridization between hydrogen fuel cell & PHS optimum combinations of PV system with various storage configurations is used. The authors demonstrate usage of Hydrogen Fuel cell & Pump Hydro storage with Solar PV systems enhances the supply-demand balance also raises the RES share and DSF significantly[15].

Loiy Al-Ghussain et. al., in continuation of the author's previous work, for the most cost-effective use of renewable energy sources, authors investigated the design of RE systems with ESS in microgrids. The results showed that the supply-demand imbalance was reduced by the integration of PHS with HFC. While PHS & HFC integration significant increase in the RES share and DSF. Integration of PHS improved the $F_R$ (RES fraction) and demand supply fraction (DSF) in the hybrid PV/wind system. The authors also discovered that system under the measured RES resources could boost the system's technical and financial viability because it was more susceptible to changes in renewable energy resources than the PV or wind system alone[16].

**d) Solar PV with Hydrogen Fuel Cell and BESS**

Benjamin Guinot et. al. shows that notwithstanding the investment cost and the limited size of the hydrogen chain, hybridization of batteries with a hydrogen storage system is adequate to eliminate the requirement for expensive and big battery storage capacity in comparison to a PV battery solution. The authors also done sensitivity analysis of the hydrogen chain and battery bank costs and found that the PV-battery arrangement is still advantageous even when the battery bank cost falls. In this study, the results also reveal the limited impact of the capital cost of the hydrogen chain. The PV-battery-hydrogen solution is more competitive than the PV-grid when sensitivity analysis done on diesel costs with rise in price of diesel[17].

Fabio Serra et. al., developed a mathematical model to predict the anticipated yearly energy outflows & energy management plan was provided in order to maximise the self-sufficiency of users of $H_2$-based MGs in applications with a high-Renewable energy penetration. The authors observed significant economic gains and determined energy prices (i.e., LCOE) which is equivalent to present grid tariff[18].

Andrea Monforti et. al. developed a model for the ideal size of a hydrogen cycle (fuel cell, electrolyser and compressed storage) and lead-acid battery energy storage system for a hybrid renewable energy based micro-grid. In a hybrid renewable Power scenario operating under an actual household load, the authors took into consideration and simulated three ESS combinations (battery-hydrogen hybrid, hydrogen and battery) and the outcomes indicate that while Overproduction (OP) are more influenced by resource availability and the loss of load (LL) is by the load itself. LL exhibits greater responsiveness to expansion of battery capacity, with superior charging and discharging performance for precise load tracking. Conversely, OP demonstrates raising of sensitivity towards an increase in $H_2$ capacity, albeit at the cost of storage round-trip efficiency[19].

**e) Solar PV and Wind power with Hydrogen Fuel Cell and BESS**

Hanqing Yang et. al. studied, in order to reduce the operating cost of ESS, a hierarchical self-regulation control was introduced, where the supervisory layer control mechanism is based on the operating costs of various ESSs. It is employed to actualize the economical distribution of ESS allocation between AC and DC aiming for its economic optimum. In the local layer control, which can increase system stability & inertia. The authors demonstrate how an AC/DC hybrid system with a single droop control approach can lower the overall system's operating costs. The results of the stepwise change in power demonstrate that, the strategy can also reduce the rate of change in frequency and voltage while increasing system inertia[20].

Feilong Fan et. al. focus on an operational framework for zero-emission MG with HHBES (hybrid battery energy storage) designed to promote hydrogen and battery energy storage in MGs towards zero emission. The authors also note that as sensitivity increases, power costs for solar photovoltaic, wind Turbine and ELs increase. This suggests that the degree of robustness of the uncertainty set increases. During the day-ahead phase,

the optimization involves planning the tie-line power interchanged with grid, the power generated by the fuel cell, and input power of EL in the most challenging scenario of intermittent renewable energy generation and unpredictable electricity demand from Electrolysers (ELs). The output of the battery is decided upon during the intra-day stage in accordance with the short-term forecast for the output of renewable energy resources and electrolysers[21].

In a nutshell, energy storage provides the stored energy at night-time. ESS maintains MG stability over fluctuations of RE sources. Hybrid MG reduce power conversion ratio & improves efficiency over conventional system. In a standalone application, hybrid storage has considerable reduction in LCOE and also enhances the supply demand balance and rises the renewable energy sources share.

## 3. GAP IDENTIFICATION:

- In the proposed study cost reduction of optimal combination of RE resources based Microgrid with various ESS is a major challenge, which is presently very high.

- A new concept of hybrid AC-DC microgrid is to avoid multiple AC-DC conversion or vice versa. It has advantages of both AC and DC grids and also takes care of both AC and DC loads. Hence, the most promising solution is to use hybrid microgrid system.

- Electrochemical energy storages such as batteries and fuel cells have one major drawback, which is its low lifetime. Therefore, by avoiding excessive and frequent energy supplying and receiving of the battery, degradation is prevented with an increase in its lifetime. The use of HESS battery lifetime is increased by reducing the involvement of the battery in fast charge and discharge cycles. The hybridization between different configurations of HESS is the most effective solutions to support RE integration to the grid & grid stability.

## 4. MOTIVATION:

- India targeted a goal of 450 GW of RE capacity by 2030 to provide electricity to all citizens and meet its COP26 commitments.
- Energy storage is essential to support grid stability and renewable energy integration into the grid.
- Hybrid AC/DC microgrids can provide reliable power supply particularly for remote rural areas which still lack electricity access. They offer high reliability, efficiency and affordable cost.
- India's Green Hydrogen Mission aims to make India a global hub for green hydrogen and achieve large $CO_2$ emission reductions and energy import savings by 2050.Green hydrogen will be critical for India to achieve a truly low-carbon economy beyond just cost savings.

## 5. DESCRIPTION OF BROAD AREA/TOPICS:

Energy storage is used to guarantee robustness of microgrids as well as stability. It also helps make the microgrid more efficient by reducing waste from renewable energy. Hybrid AC / DC microgrid is made up of individual AC / DC microgrids that are connected to each other through interlinking stages. In this proposed study, distributed generators, energy storage systems and loads are all connected to both AC and DC buses and where interlinking converters serve as the interface between the AC and DC sub grids.

Hybridization of Energy storage system optimal configurations of Solar photovoltaics & Wind Energy with different ESS combinations based on maximize of fraction of RE with landed cost of energy equals to main grid tariff.

To analyse the effect of the use of storage systems different combination (Fig.-2) of ESSs are considered with PV & wind system. Combinations are as follows-

a) BESS+ Supercapacitor (SC)

b) Hydrogen Fuel Cell (HFC) +Battery Energy Storage System (BESS)

c)HFC + Pump Hydro System (PHS)

d) BESS +SC+ HFC +PHS.

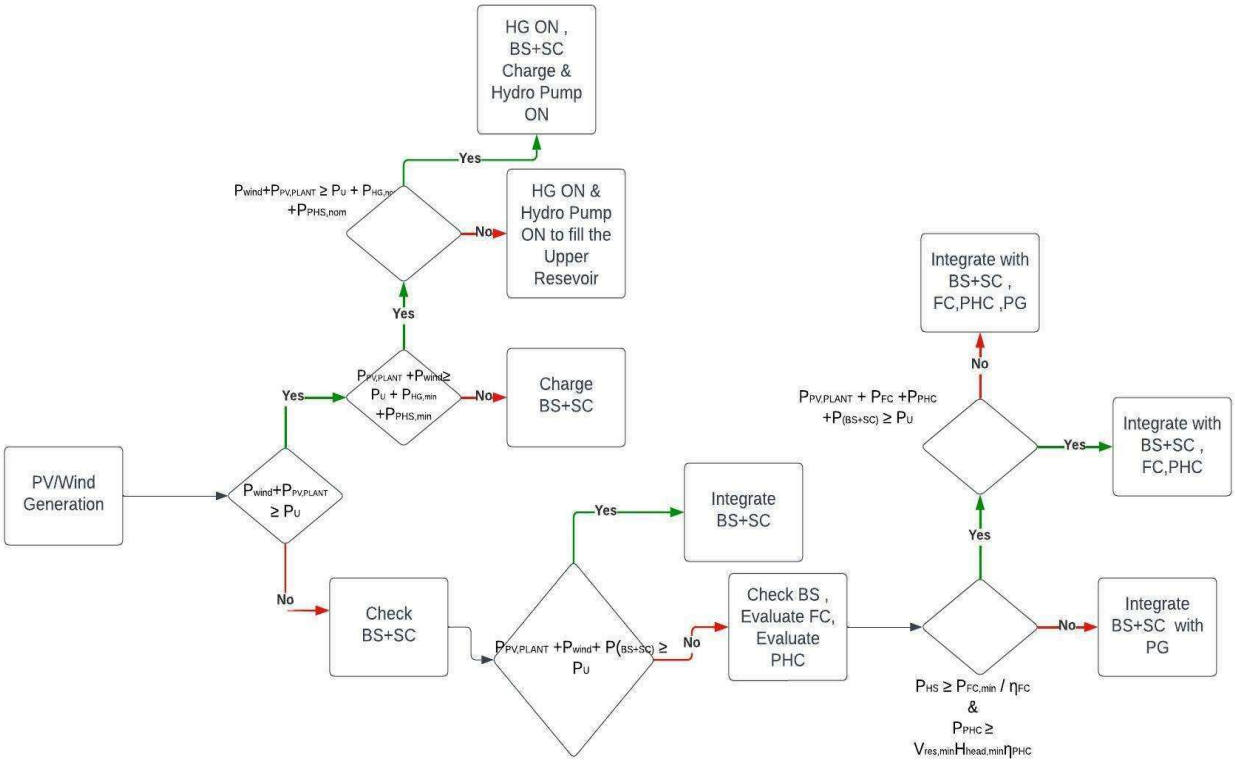


**Fig.-2** Proposed Plant logic Diagram.

U-User, PG-Public grid, HG – $H_2$ Generator, HS – $H_2$ Storage, BS -Battery Energy Storage, PHC-Pump Hydro storage, SC-Super capacitor

In the proposed study, HOMER Pro simulation software will be utilized for techno-economic evaluation of the HESS model and for sensitivity analysis of the model.

## 6. OBJECTIVES OF THE STUDY:

i) To promote different HESSs in microgrids toward zero emission by analysing a microgrid with hybrid energy storage system (HESS) for Techno-economic viability.

ii) To develop storage solutions that can bridge the energy shortfall during peak demand hours by Simulation of MG system with RE sources and HESS solutions.

iii) To enhance the technical as well as economic benefits of the HESS by optimizing RE sources and ESS.

iv) To study both the economic and technical parameters with influence of tracker-based solar photovoltaic technology on grid connected HESS.

## 7. METHODOLOGY TO BE ADOPTED:

Comprehensive simulation tools are required for implementation of techno-economic evaluation of the power system. There are various software options available for designing, simulating and optimizing for RE based systems. HOMER Pro is the most frequently used software.

By using HOMER Pro software with following steps techno-economic evaluation will be done of the proposed model.

- ✓ Electricity generation from tracker-based solar photovoltaic plant & Wind power plant
- ✓ Hybrid Energy Storage System Model and Electrical Energy Demand
- ✓ Performance Assessment of the Energy System
- ✓ Economic Assessment of the Energy System & Optimization process
- ✓ Sensitivity Analysis

## 8. DATA COLLECTION

Connected Load data (load curve) for one year will be collected from one of the major city (8760 no.s data) of India. And Solar & Wind Energy resources data will be collected from NASA resources for each month of a year through HOMER Pro/PV Syst software.

## 9. PROPOSED/EXPECTED OUTCOME OF THE RESEARCH:

A zero-emission MG supplies power to the main grid during peak pricing periods and draws power from the main grid during time of low electricity prices. Hybridization between various configurations including tracker-based PV system to identify the most suitable RES configurations with multiple storage system combinations, based on the maximisation of RE fraction ($F_R$) with landed cost of energy (LCOE) equal to tariff of main grid and optimizes the technical performances of the proposed system.

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# Analysis of Hybrid Energy Storage System Integrated with Microgrid

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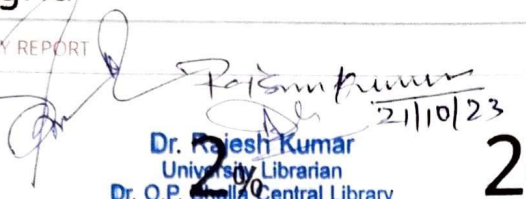

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